Finite Element Analysis of Localized Heating in Optical Substrates Due to E-beam Patterning

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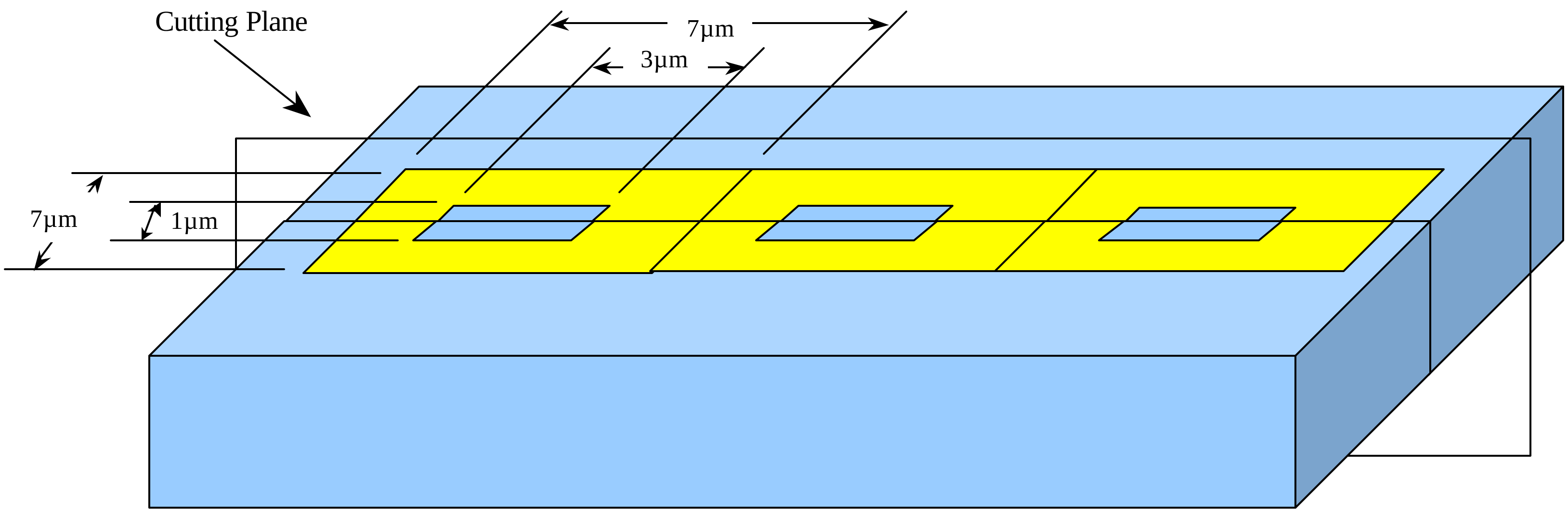
Motivation for the Research

- Very localized heating effects are beginning to play a critical role in CD control.
- Predicting the effects of various writing parameters can assist in designing for smaller feature mask patterning.
- The ability to predict these effects requires a knowledge of how the temperature affects resist properties
  - Resist sensitivity, equivalent dose, and development rate all increase with increasing temperature.
- Experimental mask writing is time consuming and occupies valuable tool time.
- Computational modeling is an alternative that not only frees up time on e-beam patterning tools, but also provides easily visualized results that would otherwise be impossible to see in experimental data.

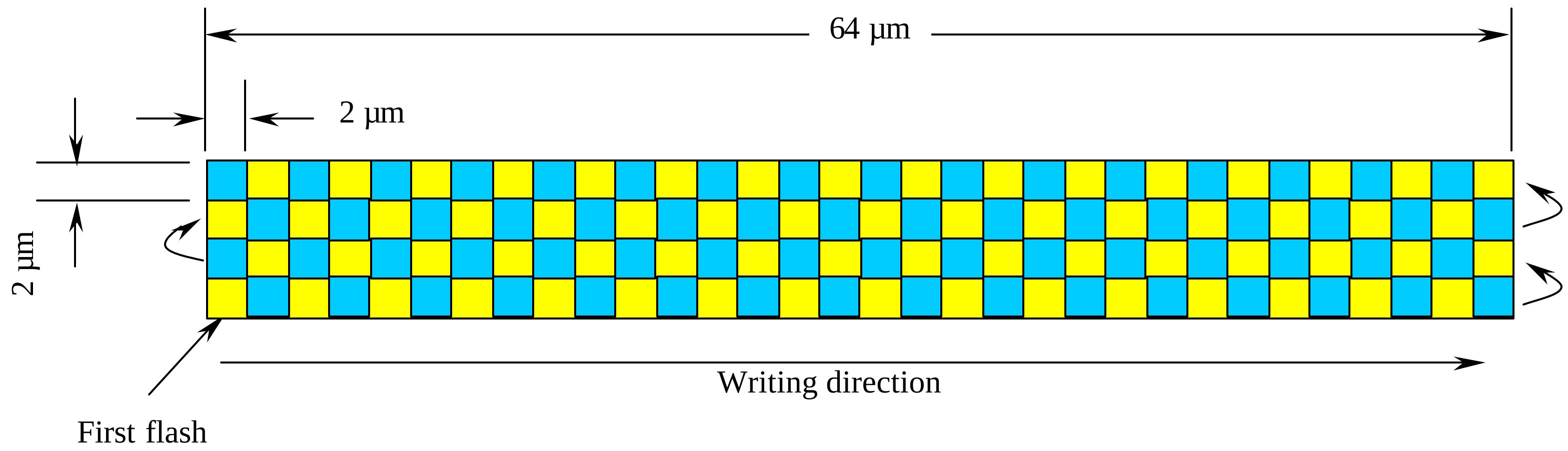
Model 1: High Resolution Three Flash Simulation



Shown above is a figure of the writing pattern used for the two simple test cases that follow:

Case I - High Current Density:	Dose	6.5 µC/cm^2
	Current Density	65 A/cm^2
Case II - Low Current Density:	Dose	6.5 µC/cm^2
	Current Density	6.5 A/cm^2

Model 2: Complete Subfield Patterning Simulation



Shown above is a schematic for the first few rows of patterning. The entire simulation is for a 64 µm × 64 µm written field and consists a total of 512 shots. The settling time between shots is 1µs. The dosage to the resist was 9.6 µC/cm^2 and was applied by a beam with an energy of 50 kV and a current density of 9.6 µC/cm^2.

UW-CMC

Material Properties

Material Property List for Model 1

Material	Thickness (µm)	Density (g/cm^3)	Thermal Conductivity (W/cm-K)	Specific Heat (J/g-K)	Emissivity
PMMA	0.40	1.19	0.0021	1.460	0.84
Chrome	0.08	7.19	0.6290	0.465	
SiO_2	30.00	2.20	0.0140	0.750	

Material Property List for Model 2

Material	Thickness (µm)	Density (g/cm^3)	Thermal Conductivity (W/cm-K)	Specific Heat (J/g-K)	Emissivity
ZEP 7000	0.45	1.10	0.0019	0.980	0.84
CrO_2N_3	0.03	5.21	0.6290	0.465	
Chrome	0.07	7.19	0.6290	0.465	
SiO_2	50.00	2.20	0.0140	0.750	

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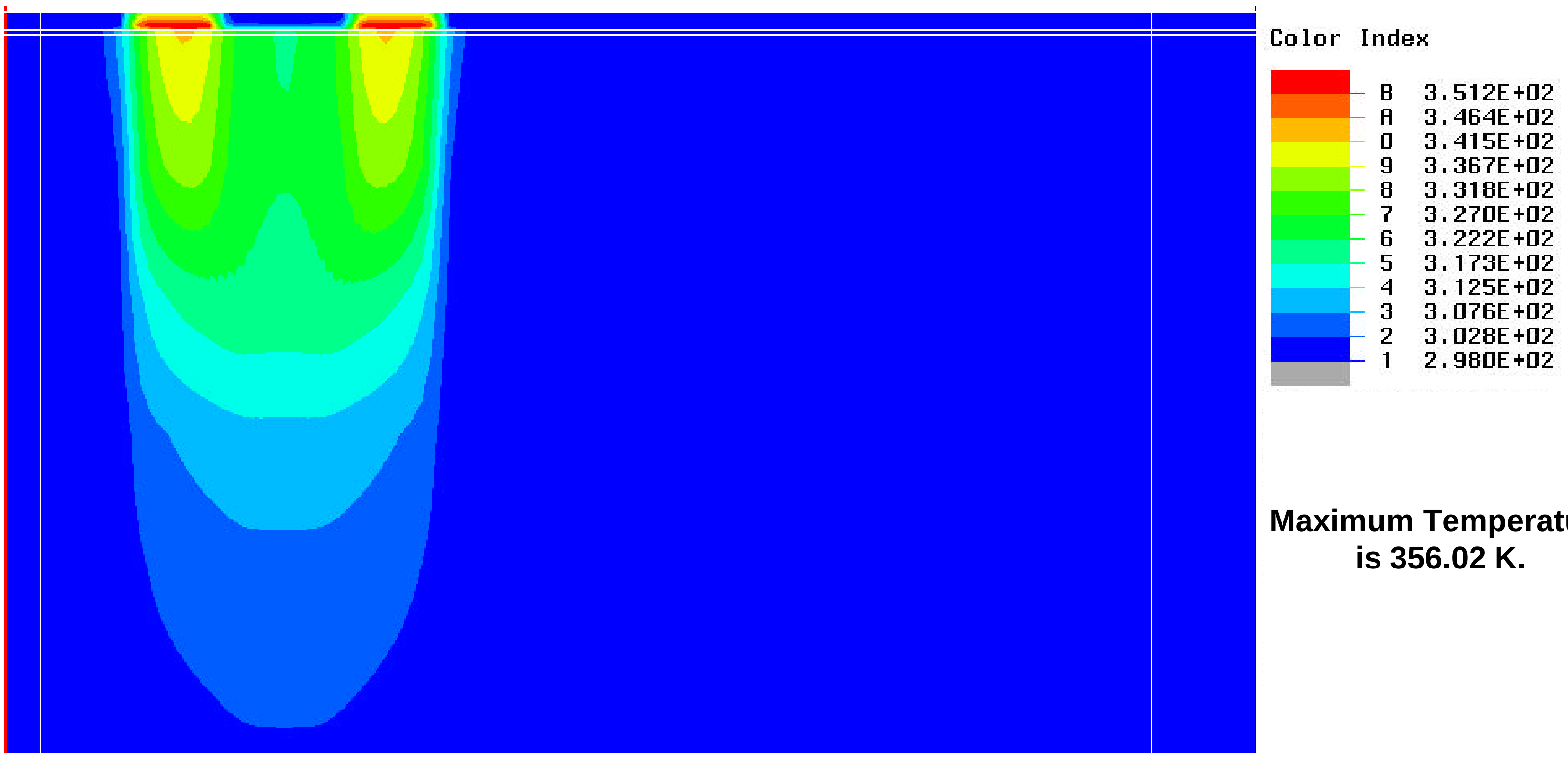
Case I – Temperature Results Across Cutting Plane

Time: 0.1 μs

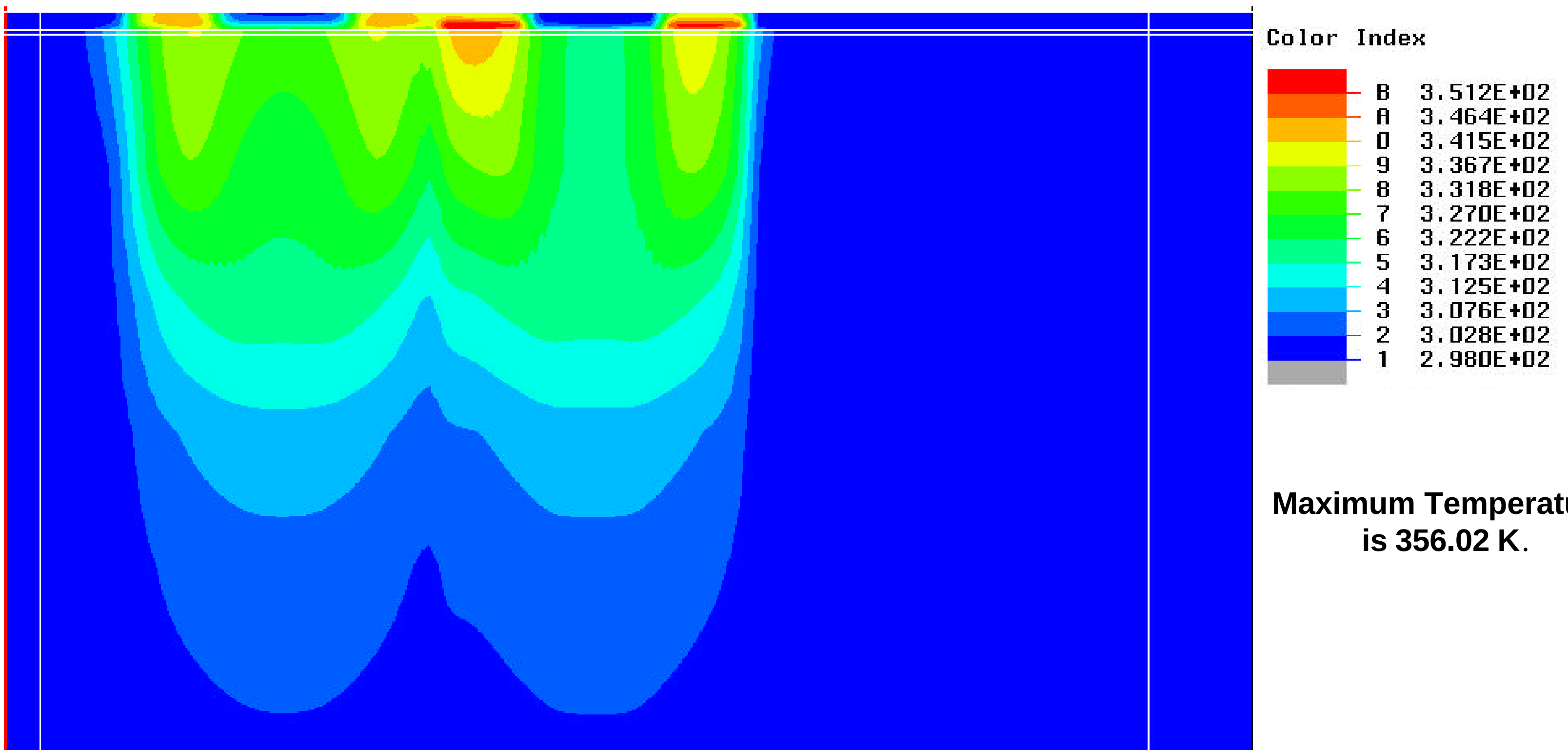


Maximum Temperature is 356.02 K.

Cross sectional temperature contours from the ABAQUS simulation. Time is at 0.1 μs. Dose is 6.5 μC/cm^2. Current density of 65 A/cm^2.

Case I – Temperature Results Across Cutting Plane

Time: 0.2 μs

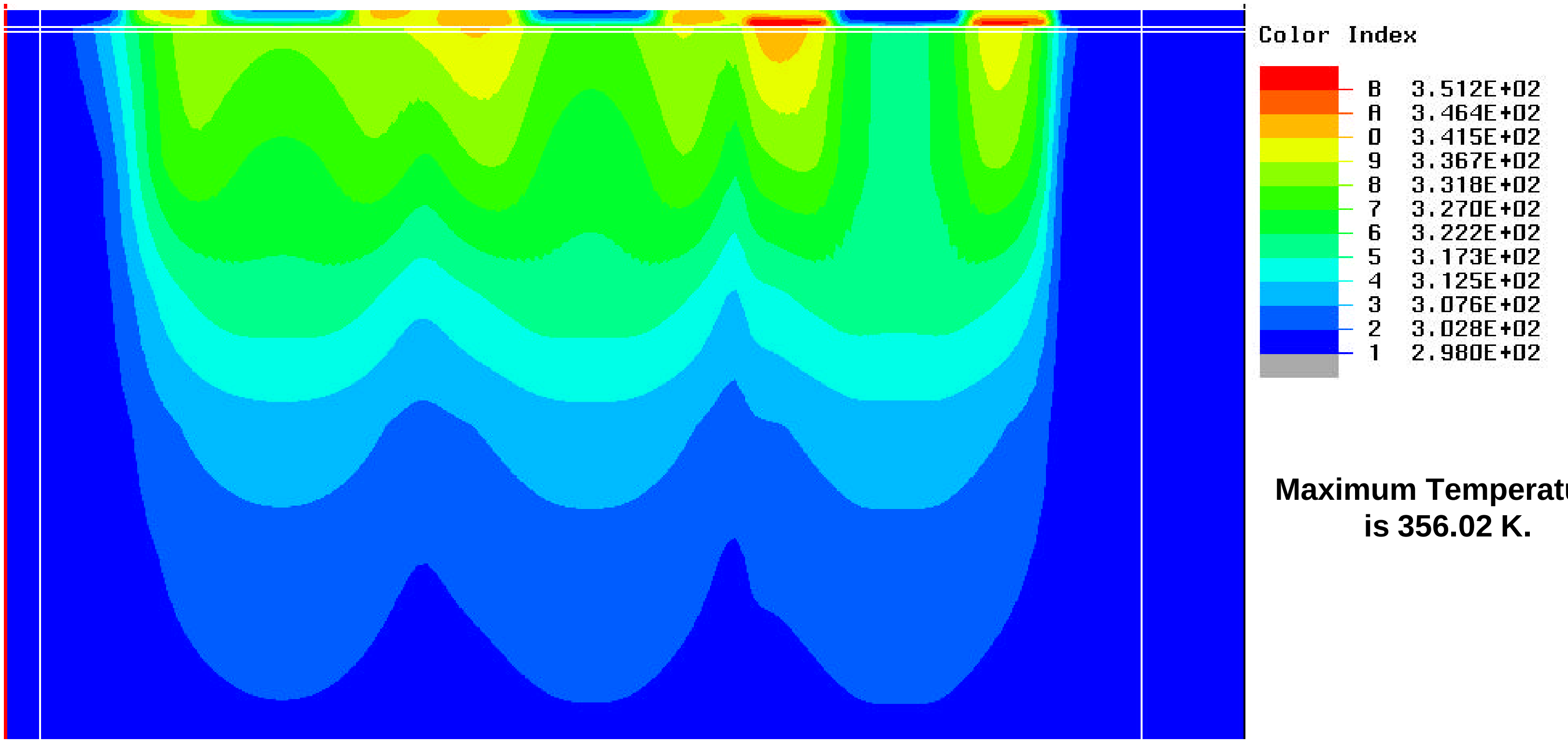


Maximum Temperature is 356.02 K.

Cross sectional temperature contours from the ABAQUS simulation. Time is at 0.2 μs. Dose is 6.5 μC/cm^2. Current density of 65 A/cm^2.

Case I – Temperature Results Across Cutting Plane

Time: 0.3 μs



Maximum Temperature is 356.02 K.

Cross sectional temperature contours from the ABAQUS simulation. Time is at 0.3 μs. Dose is 6.5 μC/cm^2. Current density of 65 A/cm^2.

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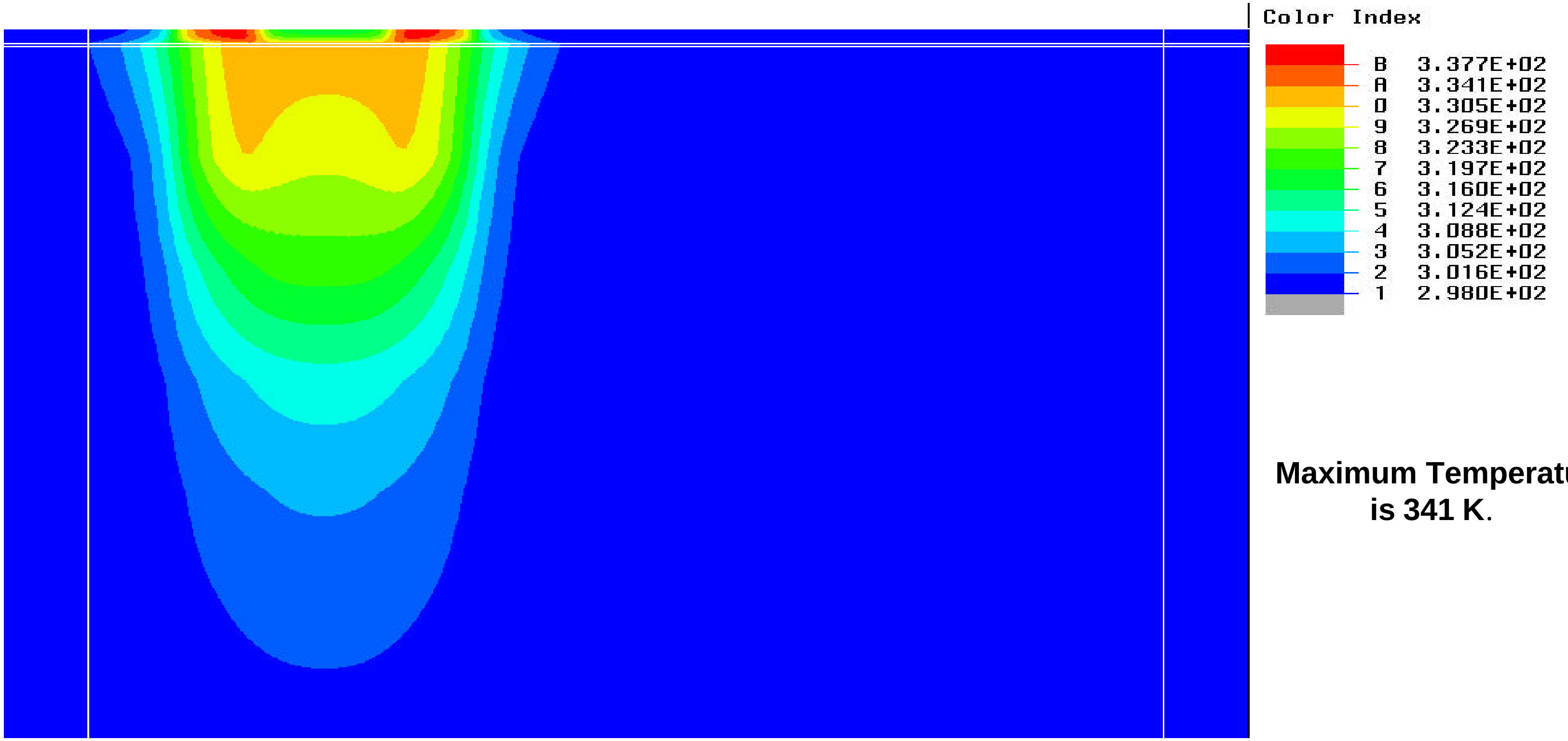
Case II – Temperature Results Across Cutting Plane

Time: 1.0 μs

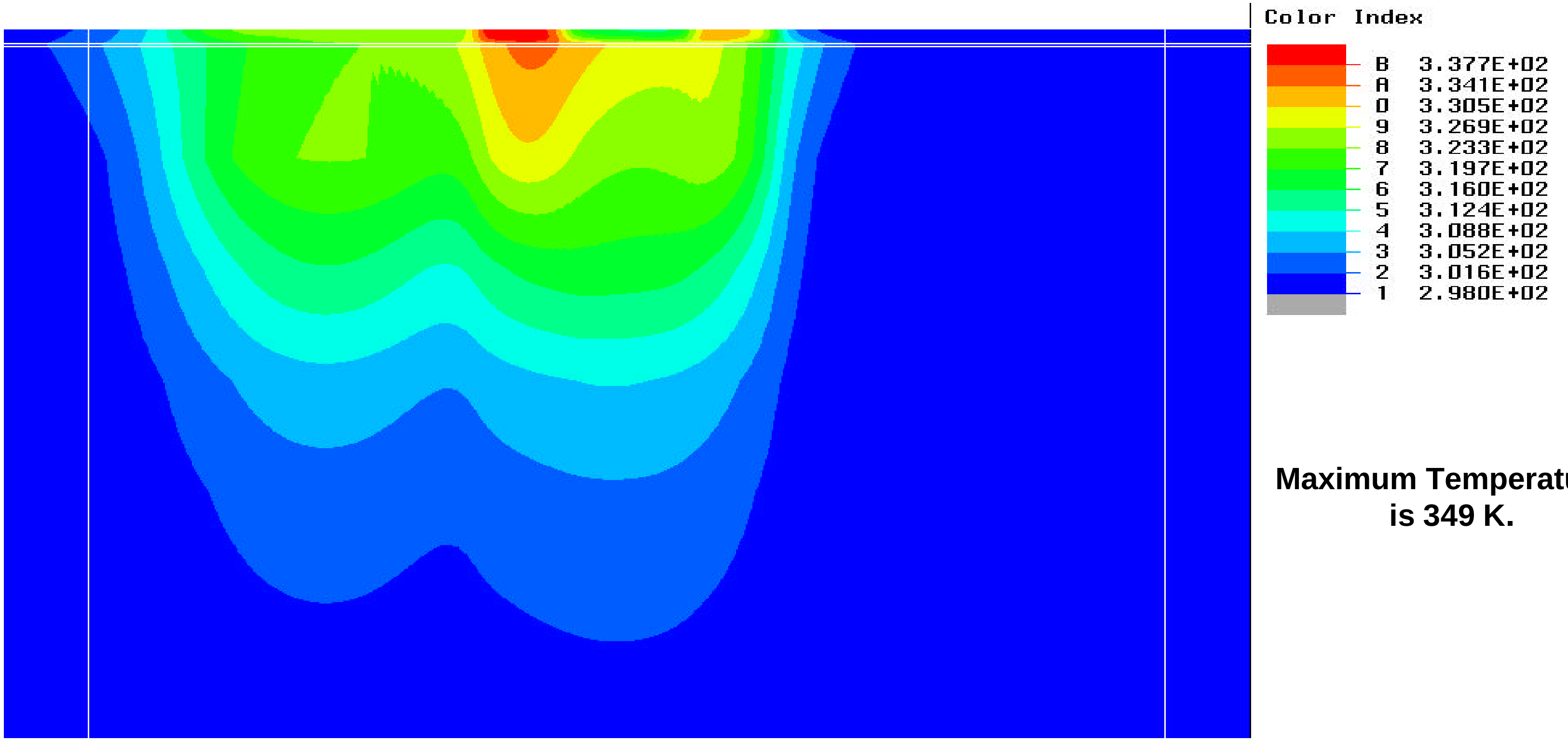


Maximum Temperature is 341 K.

Cross sectional temperature contours from the ABAQUS simulation. Time is at 1.0 μs. Dose is 6.5 μC/cm^2. Current density of 6.5 A/cm^2.

Case II – Temperature Results Across Cutting Plane

Time: 2.0 μs

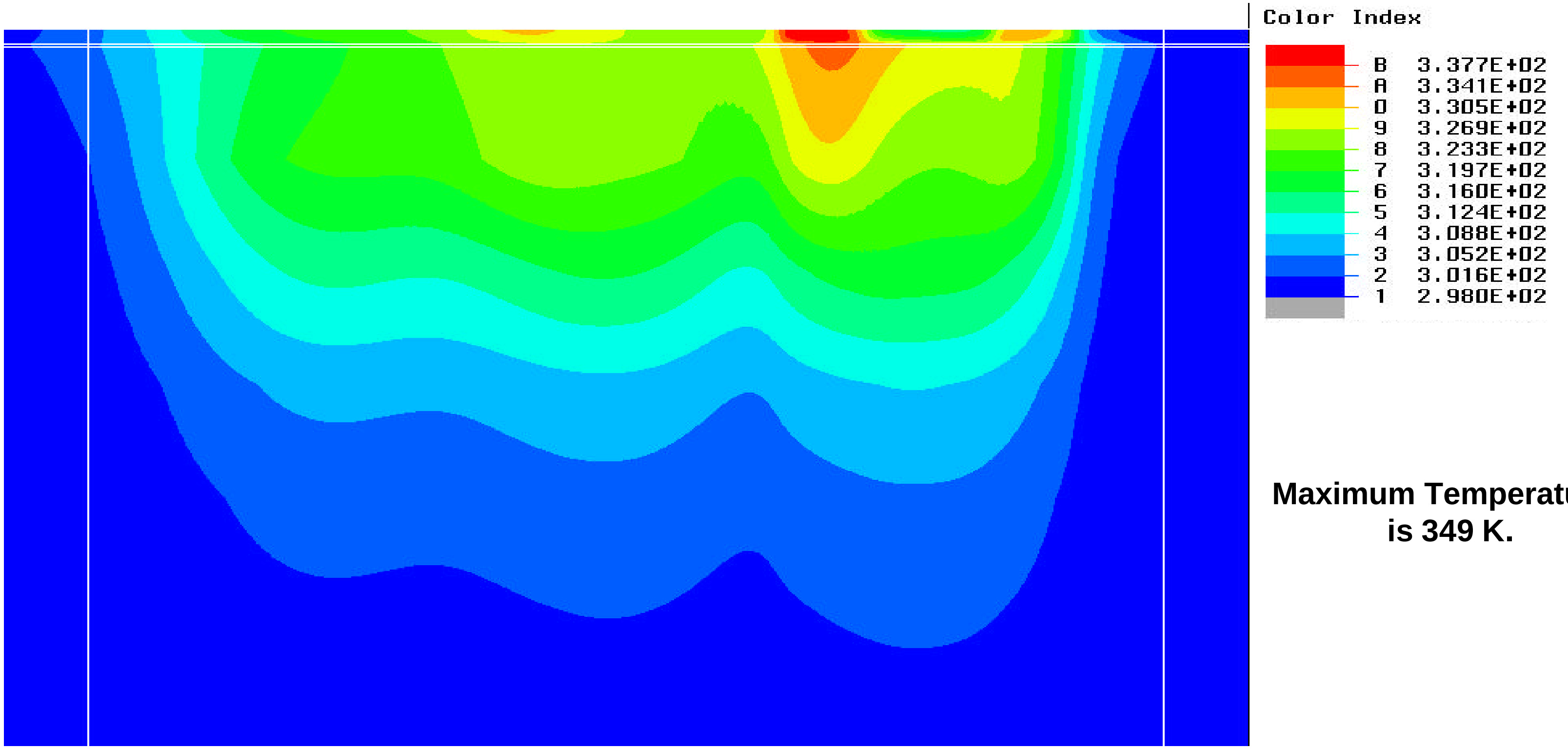


Maximum Temperature is 349 K.

Cross sectional temperature contours from the ABAQUS simulation. Time is at 2.0 μs. Dose is 6.5 μC/cm^2. Current density of 6.5 A/cm^2.

Case II – Temperature Results Across Cutting Plane

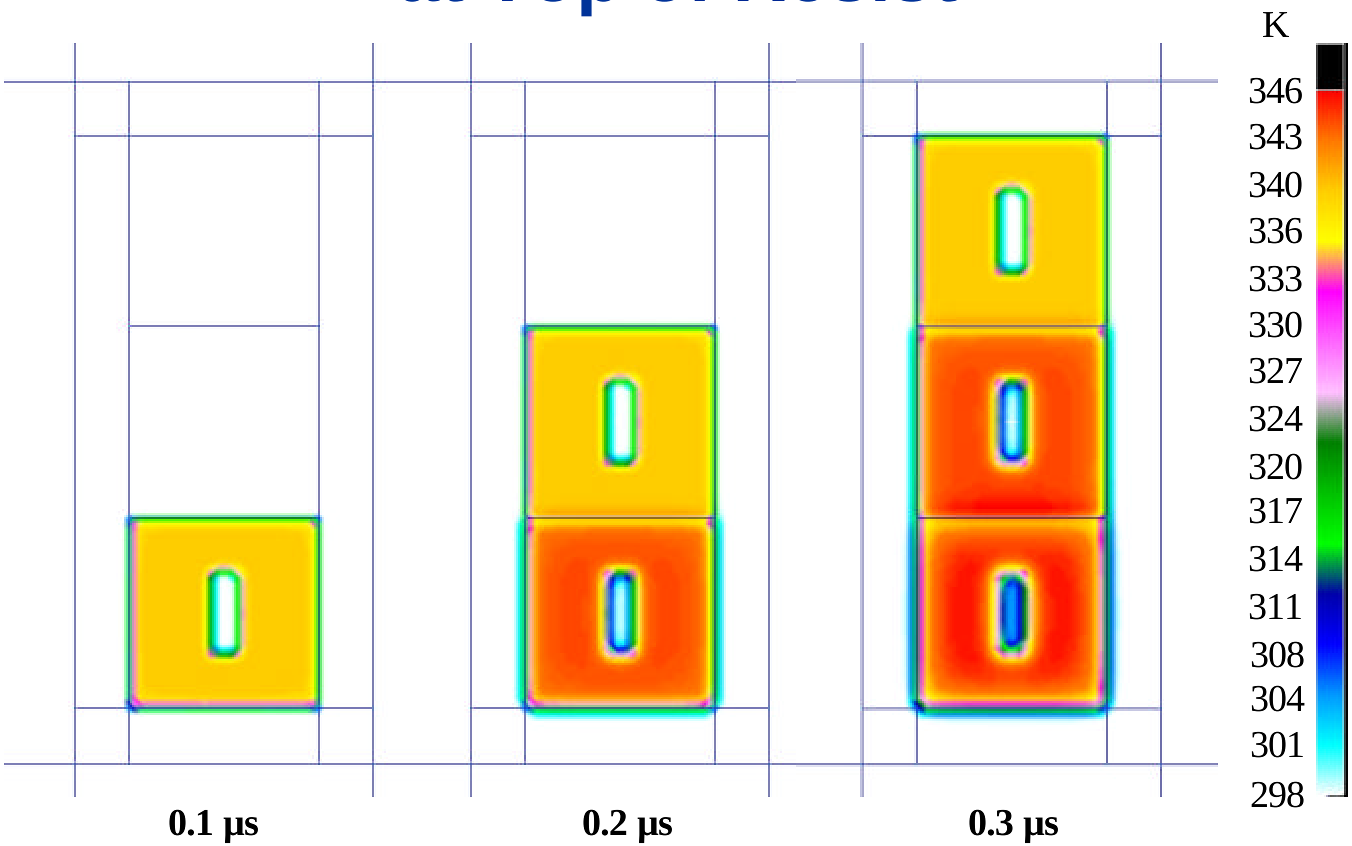
Time: 3.0 μs



Maximum Temperature is 349 K.

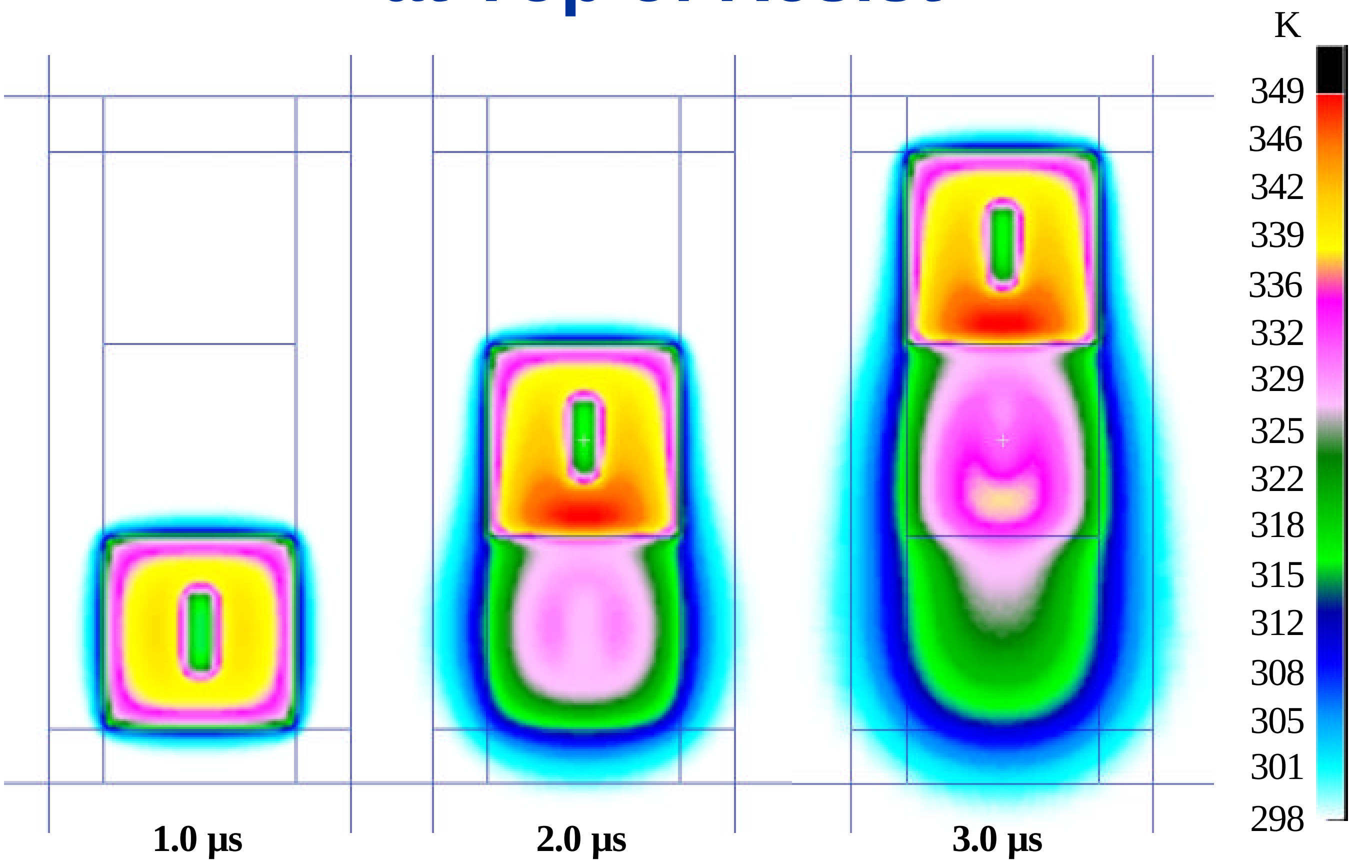
Cross sectional temperature contours from the ABAQUS simulation. Time is at 3.0 μs. Dose is 6.5 μC/cm^2. Current density of 6.5 A/cm^2.

Case I – Temperature Results at Top of Resist



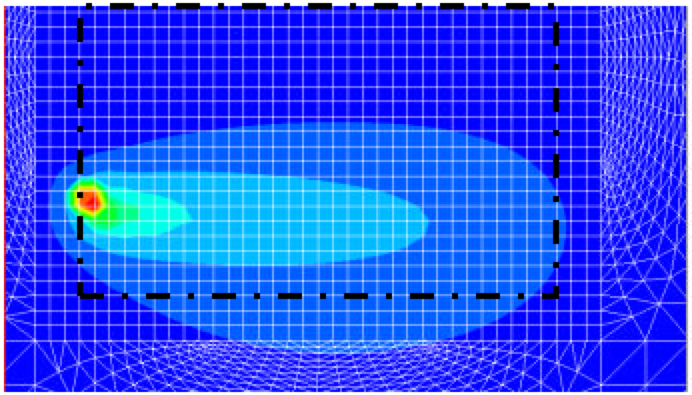
The figures present the temperature contours on the top layer of the resist at the end of (a) 0.1 μs, (b) 0.2 μs, and (c) 0.3 μs. Dose is 6.5 μC/cm^2. Current Density is 65 A/cm^2. At 0.3 μs, the familiar corner rounding phenomenon can be seen. Note that for this writing situation, the highest temperature is not at the top of the resist.

Case II – Temperature Results at Top of Resist

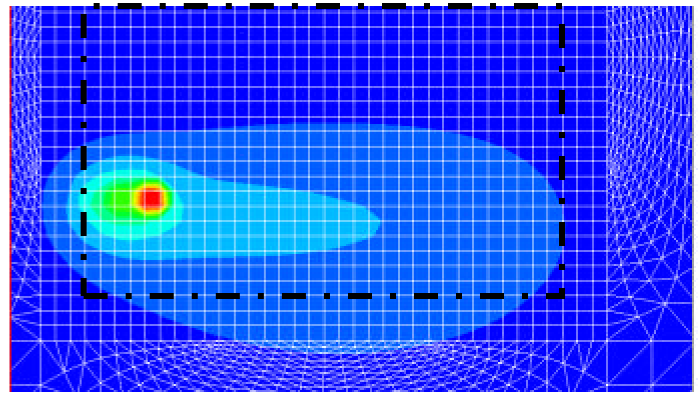


The figures present the temperature contours on the top layer of the resist at the end of (a) 1.0 µs, (b) 2.0 µs, and (c) 3.0 µs. Dose is 6.5 µC/cm^2. Current Density is 6.5 A/cm^2. The corner rounding phenomenon is prevalent in all the flashes. Note that for this writing situation, the highest temperature is at the top of the resist.

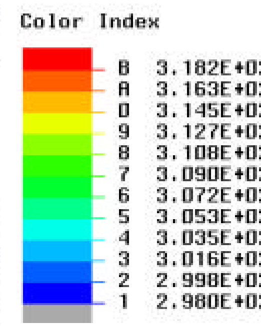
Model 2 – Temperature Results at Top of Resist at Various Times

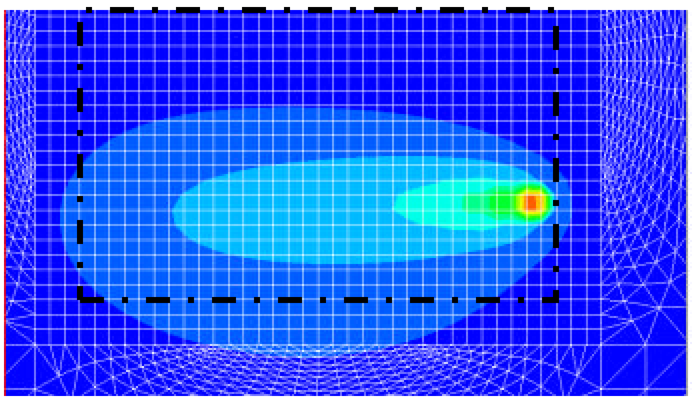


Flash #97, 193 μs into the simulation
Maximum Temperature is 322.04 K

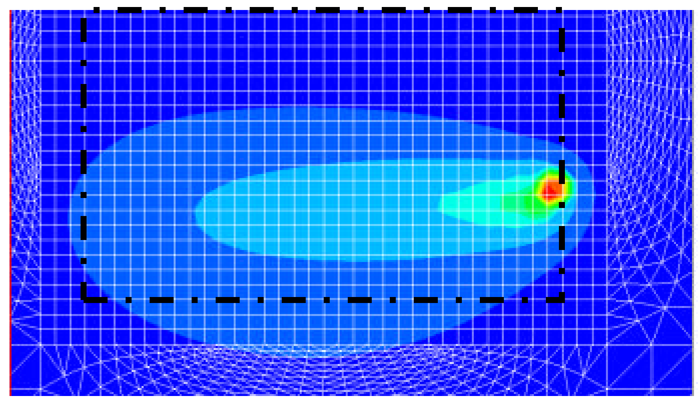


Flash #99, 197 μs into the simulation
Maximum Temperature is 319.99 K



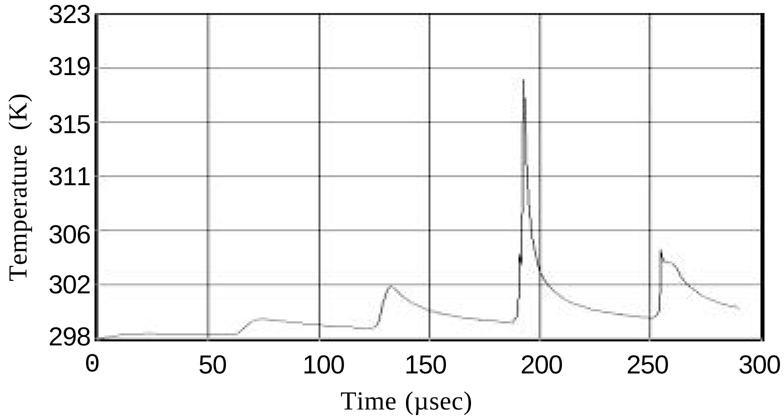


Flash #112, 223 μs into the simulation
Maximum Temperature is 316.95 K

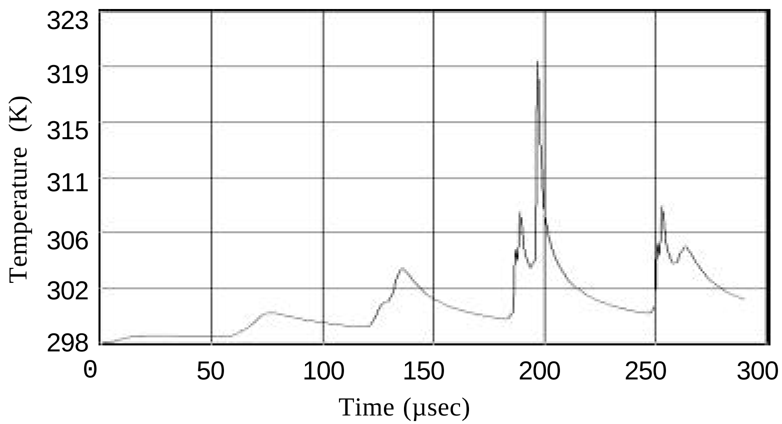


Flash #113, 225 μs into the simulation
Maximum Temperature is 322.16 K

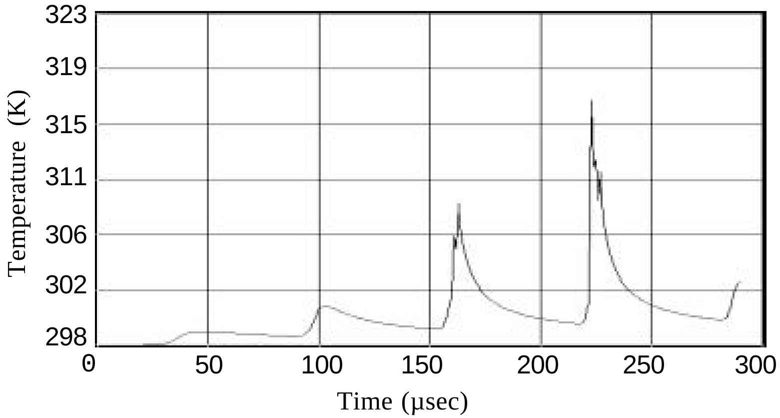
Model 2 – Temperature Histories of Select Points In the Patterned Area



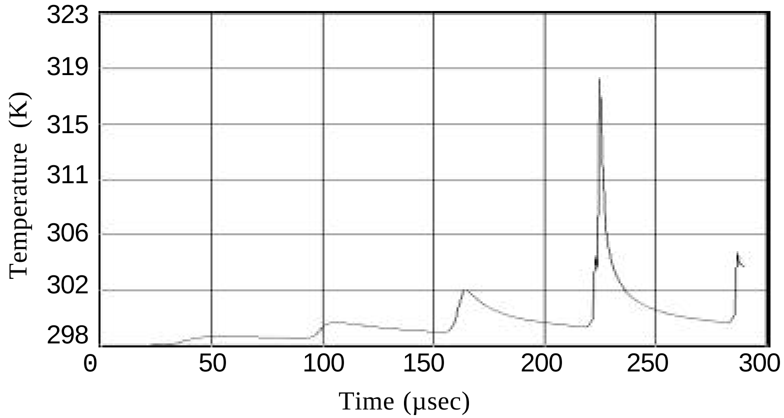
Location of flash #97



Location of flash #99



Location of flash #112



Location of flash #113

Conclusions and Future Research

- Computational modeling provides insight into the localized heating problem. It is capable of showing results that are difficult to observe in experimental methods.
- Results of the two finite element models show that the numerical simulations are able to resolve temperature details with a very fine spatial resolution, and are also capable of complete patterning schemes.
- When modeling with finite elements, the user has the ability to control all characteristics and parameters of the model (from boundary conditions to mesh sizing), giving it its greatest strength, versatility.
- Relating the temperature rise caused by e-beam patterning with an equivalent dosage to the resist will be investigated in the future. Modeling results will then be confirmed with experimental results to provide a tool that can be used to expose the problems associated with a particular pattern, shape, or writing scheme, and can also be used to optimize these parameters for higher quality patterning with greater throughput.